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MICRODISPLAY FOR PORTABLE COMMUNICATION SYSTEMS

Related Applications

This is a continuation-in-part application of U.S. Serial No. 08/741,671 filed on October 31, 1996, the entire  
5 contents of which is incorporated herein by references.

Background of the Invention

Flat-panel displays are being developed which utilize liquid crystals or electroluminescent materials to produce high quality images. These displays are expected to  
10 supplant cathode ray tube (CRT) technology and provide a more highly defined television picture or computer monitor image. The most promising route to large scale high quality liquid crystal displays (LCDs), for example, is the active-matrix approach in which thin-film transistors  
15 (TFTs) are co-located with LCD pixels. The primary advantage of the active matrix approach using TFTs is the elimination of cross-talk between pixels, and the excellent grey scale that can be attained with TFT-compatible LCDs.

Flat panel displays employing LCDs generally include  
20 five different layers: a white light source, a first polarizing filter that is mounted on one side of a circuit panel on which the TFTs are arrayed to form pixels, a filter plate containing at least three primary colors arranged into pixels, and finally a second polarizing  
25 filter. A volume between the circuit panel and the filter plate is filled with a liquid crystal material. This material will allow transmission of light in the material when an electric field is applied across the material between the circuit panel and a ground affixed to the

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filter plate. Thus, when a particular pixel of the display is turned on by the TFTs, the liquid crystal material rotates polarized light being transmitted through the material so that the light will pass through the second  
5 polarizing filter.

The primary approach to TFT formation over the large areas required for flat panel displays has involved the use of amorphous silicon, which has previously been developed for large-area photovoltaic devices. Although the TFT  
10 approach has proven to be feasible, the use of amorphous silicon compromises certain aspects of the panel performance. For example, amorphous silicon TFTs lack the frequency response needed for high performance displays due to the low electron mobility inherent in amorphous  
15 material. Thus the use of amorphous silicon limits display speed, and is also unsuitable for the fast logic needed to drive the display.

As the display resolution increases, the required clock rate to drive the pixels also increases. In  
20 addition, the advent of colored displays places additional speed requirements on the display panel. To produce a sequential color display, the display panel is triple scanned, once for each primary color. For example, to produce color frames at 20 Hz, the active matrix must be  
25 driven at a frequency of 60 Hz. In brighter ambient light conditions, the active matrix may need to be driven at 180 Hz to produce a 60 Hz color image. At over 60 Hz, visible flicker is reduced.

Owing to the limitations of amorphous silicon, other  
30 alternative materials include polycrystalline silicon, or laser recrystallized silicon. These materials are limited as they use silicon that is already on glass, which generally restricts further circuit processing to low temperatures.

Integrated circuits for displays, such as, the above referred color sequential display, are becoming more and more complex. For example, the color sequential display is designed for displaying High Definition Television (HDTV) formats requiring a 1280-by-1024 pixel array with a pixel pitch, or the distance between lines connecting adjacent columns or rows of pixel electrodes, being in the range of 15-55 microns, and fabricated on a single five-inch wafer.

10 Summary of the Invention

In accordance with the invention, the cost and complexity of high resolution displays is significantly reduced by fabricating multiple integrated displays of reduced size on a single wafer and then dicing the wafer to produce a plurality of display devices.

The displays are then assembled with appropriate magnifying optics to form a portable display system of low cost and reduced size. Included in the optics is a magnification system which compensates for the small image size by magnifying and projecting the image at an appropriate distance for viewing.

In preferred embodiments, the microdisplay, because of its small size and weight, can be used as a hand-held communication system such as a pager, a wireless mobile telephone, or alternatively, as a head-mounted display. The display can provide a visual display suitable for data, graphics or video and accommodate standard television or high definition television signals. The system can optionally include circuitry for cellular reception and transmission of facsimile communications, can be voice activated, can include a mouse operated function, provide internet access, and can have a keyboard or touch pad for numeric or alphabetic entry. The telephone or hand-held unit can be equipped with a camera or solid state imaging sensor so that images can be generated and transmitted to a

remote location and/or viewed on the display. Also the telephone user can call to access a particular computer at a remote location, present the computer screen on the micro display, access specific files in the computer memory and  
5 download data from the file into a memory within the telephone or a modular memory and display unit connected to the telephone. The telephone can be connected to a local computer or display and the data from the file can be loaded into the local memory.

10 In a preferred embodiment of the invention, a light emitting diode (LED) device is used to illuminate the display. For transmission displays the LED device operates as a backlight and can include a diffuser. An LED device can also be used as a light source for a reflective display  
15 in another preferred embodiment of the invention. The displays are preferably liquid crystal displays using a nematic liquid crystal material. Consequently, controlling the time domain is not necessary to obtain grey scale.

For the purposes of this application, a microdisplay  
20 is defined as a display having at least 75,000 pixel electrodes and an active area of less than  $158 \text{ mm}^2$ , where the active area of the display is the area of the active matrix circuit that generates an image, including all of the pixel electrodes but not including the driver  
25 electronics and the border area for bonding and sealing of the liquid crystal display. For example, the array can be at least  $320 \times 240$ ,  $640 \times 480$  or higher. A preferred embodiment of the microdisplay has an active area of  $100 \text{ mm}^2$  or less, and is preferably in the range between  $5 \text{ mm}^2$  and  
30  $80 \text{ mm}^2$ . The pixel pitch for these displays is in the range of 5 - 30 microns and preferably in the range between 5 and 18 microns. By utilizing pixel pitches of less than 18 microns smaller high resolution displays are now possible.

For displays of this size and resolution to be read by  
35 a user at distances of less than 10 inches (25.4 cm) there

are specific lighting and magnification requirements. For a 0.25 inch (6.35 mm) diagonal display, for example, the LED device preferably includes a plurality of LEDs coupled to a diffuser. The lens used to magnify the display image has a field of view in the range of 10 - 60 degrees, and preferably at least about 16 degrees - 22 degrees, an ERD in the range of about 25 mm - 100 mm and an object distance of between about 1.5 and 5 feet (152.4 cm). A color field sequentially operated LED backlight system can use a plurality of LEDs with a two or four sided reflector assembly to concentrate the light through the liquid crystal display. A preferred embodiment can use at least two LEDs, or as many as six or more of each color, to provide the desired brightness level. Alternatively the LEDs can be arranged around the periphery of a transmissive display and directed down into a conical reflector that directs the backlighting through the display in concentrated form.

The display can be operated using a color sequential system as described in U.S. Patent Application Serial No. 08/216,817, "Color Sequential Display Panels" filed on March 23, 1994, the entire contents of which is incorporated herein by reference, discloses an active matrix display in which the control electronics is integrated with the active matrix circuitry using single crystal silicon technology. The control electronics provides compressed video information to produce a color image for data, a still image or a video image such as a television image on the display.

The microdisplays described herein can be used in head mounted displays, including color sequential systems as described in greater detail in U.S. Application Serial No. 08/410,124 filed on March 23, 1995, the entire contents of which is incorporated herein by reference. Further details regarding the drive electronics suitable for a microdisplay

can be found in U.S. Serial No. 08/106,416 filed on August 13, 1993, the entire contents of which is incorporated herein by reference. A preferred embodiment of the display control circuit utilizes an "under scanning" feature in which selected pixels are rapidly turned on and off to enhance edge definition and emulate a higher resolution display. The display control circuit can also utilize a panning capability so that a small portion of a displayed image can be selected, by mouse operation for example, and presented using the entire microdisplay image area thereby allowing the user to perceive smaller displayed features. This can also be used to view selected portions of a high resolution image, such as a portion of a 640 x 480 image on a 320 x 240 microdisplay.

15 Brief Description of the Drawings

The above and other objects and features of the invention will be better understood and appreciated by those skilled in the art in view of the description of the preferred embodiments given below in conjunction with the accompanying drawings, in which:

Figure 1 is a perspective view of a single wafer having a plurality of display devices formed thereon in accordance with the invention.

Figure 2A is a schematic illustration of a die for an integrated active matrix panel display which includes optional control signal circuitry therein.

Figure 2B and 2C illustrate preferred embodiments of display control circuits in accordance with the invention.

Figure 2D illustrates a method for selectively displaying an image on a display in accordance with the invention.

Figures 3A and 3B are exploded views of a video display device and pager in accordance with a preferred embodiment of the invention.

Figures 4A-4I are exterior views of hand-held imaging devices in accordance with the invention.

Figure 5A is a side view of a lens suitable for magnifying a microdisplay in accordance with the invention.

5     Figure 5B is a side view of a multi element lens providing an increased field of view.

Figure 5C is a cross-sectional view of a display assembly with a fixed lens.

10     Figure 5D is a schematic view of an LED backlighting system for a liquid crystal display in accordance with the invention.

Figure 5E - 5J illustrate additional preferred embodiments of a backlighting system in accordance with the invention.

15     Figure 6 is an optical diagram of a lighting system for a reflective liquid crystal display.

Figure 7A-7C illustrates preferred LED backlighting systems for a transmission type display.

20     Figure 8 is a perspective view of a preferred embodiment mobile telephone having a display device in accordance with the invention.

Figures 9A-9J are illustrations of further preferred embodiments of a telephone microdisplay system in accordance with the invention.

25     Figures 10A and 10B illustrate another preferred embodiment of a telephone microdisplay system.

Figure 11 illustrates another preferred embodiment of a telephone microdisplay system in accordance with the invention.

30     Figures 12A and 12B illustrate rear views of another preferred embodiment of a telephone microdisplay.

Figures 13A-13C are side cross-sectional, front, and front cross-sectional views of a hand held rear projection display system in accordance with the invention.

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Figures 14A-14B illustrate a body worn, hand operated display system in accordance with the invention.

Figure 15A is a perspective view of a head-mounted display system of the invention.

5        Figure 15B is a partial schematic perspective view of the system of Figure 15A emphasizing additional features of the invention.

Figure 15C is a schematic perspective of the system of Figure 15A which emphasizes certain aspects of the  
10        invention.

Figure 15D is a schematic perspective view of the headband and pads of Figure 15C.

Figure 15E is a partial schematic side view of the system of Figure 15A.

## 15        Detailed Description of the Invention

### High Resolution Active Matrix MicroDisplay

A preferred embodiment of the invention utilizes a process of making a plurality of flat panel displays 10 in which a large number of active matrix arrays 14 are  
20        fabricated on a single wafer 12 as illustrated in connection with Figure 1. The number of displays fabricated on a single wafer depends upon the size of the wafer and the size of each display. A preferred embodiment of the invention, for example, uses a high resolution  
25        display having an imaging area of the display with a diagonal of 0.5 inches (12.7 mm) or less. For a four inch wafer, forty separate displays can be fabricated on a single four inch wafer. Where each display has a diagonal of about 0.25 inches (6.35 mm), 80 displays can be  
30        fabricated on a single wafer, over 120 displays can be fabricated on a five inch wafer, and 400 displays can be fabricated on an 8 inch wafer.

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By fabricating a large number of small high resolution displays on a single wafer the manufacturing yield can be substantially increased and the cost per display can be substantially reduced.

5 To obtain monochrome resolutions of at least 75,000 pixels (e.g. a 320 x 240 array) suitable for displaying an NTSC television signal on a 0.25 inch diagonal display the pixel electrodes are preferably on the order of about 15 microns in width or less. To obtain a monochrome  
10 resolution of at least 300,000 pixels (e.g. 640 x 480 array) on a 0.25 inch diagonal display the pixel electrodes preferably have a width of about 8-10 microns.

These small high resolution displays require magnification such that when held in a user's hand within  
15 the range of 0.5 inches to 10 inches of the user's eye, a clear image is provided.

Referring now to Figure 2, an integrated circuit active matrix display die is shown schematically which has been diced from a single wafer along with selected number  
20 of replicated circuits. Incorporated into the circuit 100 are scanner circuits 42a, 42b, 42c, 42d, along with pixie driven circuits 44a, 44b, 44c, 44d, select scanner circuits 46a, 46b and a display matrix circuit 90.

Further details regarding the fabrication of each die  
25 on a wafer can use the methods described in U.S. Patent No. 5,256,562, the contents of which incorporated herein its entirety by reference.

By fabricating a selected number of circuits 100 on a single wafer, the circuit yield from a single wafer is  
30 greatly enhanced at the expense of reduced display area. However, this area disadvantage is overcome by magnifying and projecting the display image as will be described herein.

A video signal bus 35-1 through 35-16 carries analog  
35 video signals from digital to analog amplifiers (not shown)

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to column drivers 44a-d. Because signal interference and signal loss can occur as the analog video signal cross each signal line in the signal bus 35, the channels of video signals are arranged to reduce interference. As

5 illustrated, there are four column drivers 44a-44d, two column drivers 44a,44b at the top of the active matrix circuit 90 and two column drivers 44c,44d at the bottom of the active matrix circuit region 90. Each channel is allocated to one of the column drivers 44 such that each

10 column driver 44 receives video from four channels. The top column drivers 44a,44b receive video from the channels that drive the odd-numbered pixel columns and the bottom column drivers 44c,44d receive video from the channels that drive the even-numbered columns. As shown, no video signal

15 has to cross the path of more than one other video signal.

The illustrated arrangement of column drivers is particularly suited for edge-to-center and center-to-edge video writing, although the data can also be written from left-to-right or right-to-left. It should be understood

20 that more or less than four column drivers 44 can be employed in preferred embodiments of the invention. For applications having resolutions of 320 x 240 or 640 x 480 it is desirable to use single column and row drivers to drive the display. For high speed, high definition

25 displays more can be used to improve performance.

The data scanners 42 a-d are responsive to a pixel data signal 142 and a pixel clock signal 143 from a control signal generator (not shown). The data scanners 42a-d can use a shift register array to store data for each scan. An

30 odd shift register array can be used to store data to odd column pixels and an even shift register array can be used to store data to even column pixels. As illustrated, there are left and right odd data scanners 42a,42b and left and right even data scanners 42c,42d.

The column drivers 44 selected by the data scanner 42 transmit video data to a selected column of C pixels in the active matrix circuit 90. The select scanner 46 controlled by a control signal generator determines by control lines 5 which pixels accept this column data.

To reduce signal loss across the active matrix region 90, the select lines are driven from both sides by select scanners 46a and b. As viewed in Figure 2A, a left select scanner 46a and right select scanner 46b are connected to 10 the select data line 146 and the select clock line 147. A third enabling line 148 can also be used for specific applications. The left select scanner 46a provides a select line signal at the end of the select line nearest the lowest-valued pixel column ( $C_1$ ) and right select 15 scanner 46b provides a select line signal at the end of the select line nearest the highest-valued pixel column ( $C_N$ ). Thus, an identical select line signal is supplied at both ends of the select line.

Although static shift registers can be used, the shift 20 registers of the data scanner 42 and the select scanners 46 are preferably implemented as dynamic shift registers. The dynamic shift registers rely on capacitor storage without leakage. However, dynamic shift registers are susceptible to leakage, especially when they are exposed to light. 25 Hence, light shields are needed to protect the scanners 42a - 42d, 46 from exposure to light. Similarly, light shields are also used to protect the transmission gates 44 and pixel columns  $C_1$ - $C_N$ .

For further information regarding the input signals to 30 the circuit 100, reference is made to the above-cited U.S. patents and applications.

In a preferred embodiment of the invention, the panel drive circuitry of Figure 2A is fabricated as an integrated circuit along with the active matrix circuit 90. The 35 integrated circuitry is preferably fabricated in single

crystal silicon having a silicon-on-insulator (SOI) structure using the fabrication and transfer procedures described previously in the aforementioned U.S. Patent No. 5,256,562. By fabricating the row and column drive  
5 circuitry 42a-42d, 44a-44d, 46a, 46b as well as the scanners in single crystal material along with the active matrix circuit 90, the size of the display panel is not constrained by the connecting pins for the various discrete components. The integrated fabrication also increases the  
10 operating speed of the display relative to displays constructed from discrete components. Furthermore, the drive circuitry can be optimized to increase display performance. For example, it is easier to construct a small 1280H x 1024V display panel with dual select scanners  
15 through integrated fabrication than it is using discrete components.

The pixel electrodes in a preferred embodiment are between 60 and 250 microns square. Consequently, a 1280H x 1024V active matrix with the control system can be  
20 fabricated such that there are at least 40 such integrated circuits on a five inch wafer, for example.

A preferred embodiment of a display control circuit for a color sequential microdisplay is illustrated in connection with Figure 2B. The display control circuit 102  
25 receives an analog composite signal 103 such as a television or VCR video signal at converter 105. Converter 105 can be a commercially available chip, such as the Sony CXA1585, which separates the signal 103 into red, green and blue components. The three analog color components are  
30 converted into digital signals by three respective analog to digital (A/D) converters 106. The three color digital signals are stored in red 107, green 108, and blue 109 memory circuits. Circuits 107, 108 and 109 can be DRAM frame buffers that are connected to the timing circuit 110.  
35 Timing circuit 110 can be connected to the telephone

processor 104 by an interface bus and receives horizontal and vertical synchronization signals along lines 119 from converter 105. Circuit 110 controls the sequential flow of each color frame onto the display by sending video data  
5 from each memory 107, 108, 109 onto the display and coordinating actuation of the backlight 111 along lines 115 for each primary color. Lines 114 provide control of hue and contrast of the resulting image. Lines 116, 117 and 118 are used to control the row and column driver circuits  
10 within display circuit 112. Lines 116 and 117 control horizontal shift and vertical shift of the data as it is read onto the display and allow the user to invert the image on the display. This can be useful for the telephone user who may select one hand to hold the telephone during  
15 use and simply press a button on the housing so that the image is inverted for presentation to the eye of the user when electing to hold the telephone speaker in the other hand adjacent to the user's ear.

Lines 118 control vertical and horizontal pulse, vertical and horizontal clock, even and odd row enable  
20 signals and the horizontal multiplying pulse signal. Digital to analog converters 106, 113, memories 107, 108, 109, connector 105 and control circuit 110 can be mounted on a common circuit board with display 112, or they can be  
25 split onto separate circuit boards or integrated circuits within the telephone housing or the docking element housing described in greater detail below depending on the geometry and operational requirements of the specific embodiment.

Another preferred embodiment of a display control  
30 circuit is illustrated in connection with Figure 2C. In this embodiment, a digital circuit 120 is used to control color sequential display operation. The processor 104 receives serial digital image data at 121 and sends display data to memory 124. An optional additional flash memory  
35 circuit 125 can also be included to store graphics data

where that is in addition to text stored at 124. Timing control circuit 122 receives clock and digital control signals from processor 104 and transmits control signals to the backlight 111 and display 112 along lines 115, 116, 5 117, and 118, respectively. Lines 128 direct ready, reset, write enable, output enable, color enable, address and data signals to memory to control deliver of image frames to the display 112.

Power management circuit 123 receives control signals 10 along line 126 from circuit 122 to lower power consumption of the circuit 120. Circuit 123 is used to control power during display operation. This capability arises from the use of a transferred thin film active matrix circuit described previously which has an ability to store charge 15 between vertical synchronization pulses. This storage capacity enables lower power consumption of the display and backlight at less than 0.2 Watts. Thus, after a frame of data is written on the display, power is lowered until the next frame is written. This lengthens battery cycle time 20 of portable communication devices as described herein.

Figure 2D illustrates a method of displaying information on the display in which large amounts of information are contained in each image. For such high information images it may be desireable to enlarge a 25 selectable portion of that image on the display. For example, the full image 130 has a region 131 in which a cursor 133 can be positioned. The user can position the cursor using a mouse or button control element anywhere within region 131 and identify a subregion 132. The user 30 selects the image of subregion for display on the full display area.

A preferred embodiment in the form of a stand-alone video display device 20 featuring a liquid crystal display incorporating the actual matrix display circuit 100 will

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now be described in connection with the exploded views of Figures 3A and 3B.

a ~~paper~~ In Figure 3A, a portable imaging device such as a pager is illustrated having a housing including a top 40 and a bottom 44 with a door 50 for access to a battery 48. The battery 48 provides power to the circuit board 42, the display 24 and the backlight 22. The pager can be operated by controls 38 or push buttons accessible through one of the housing surfaces that actuate display functions. An optical system 20 is positioned within the housing and includes a backlight 22, preferably an LED backlight, a transmission liquid crystal display 24, a focusing mechanism including a knob 28 that the user rotates to move the tunnel 30 relative to the optic slide 26, a lens assembly 32, and a cover glass 34.

Preferred embodiment of hand held display devices are illustrated in connection with Figures 4A - 4I. Figure 4A is a perspective view of a preferred embodiment of a pager system 150 having two display viewing areas 152 and 154 within a housing 155. Viewing area 152 has a lens through which the user views a microdisplay as described previously. A second flat panel display without magnification is viewed by the user at 154. The second display is a simple low resolution numeric and/or alphabetic display to read telephone numbers or scrolled numbers or messages. The microdisplay magnification can be adjusted at switch 158. The displays are operated by switches 156, 157. As seen in the rear view of Figure 4B, the rear surface 162 of housing 155 is thicker in that portion containing the microdisplay and the battery. The sideview of the housing 155 shown in Figure 4C illustrates a clip 160 that is used to fasten the device to the clothing of the user. The clip 160 is attached to the bottom surface 164 of the housing 155.

Another preferred embodiment of a hand-held viewing device 170 is illustrated in the perspective view of Figure 4E. A first display is seen through lens 172 with magnification being adjusted by knob 174. A second display 5 180 as described above is positioned on the same side of the device 170 as the lens 172 for ease of viewing. The displays are operated by switch 176 and buttons or control elements 178. A top view is illustrated in Figure 4F showing ridges 184 that accommodate the fingers of the user 10 and the second display switch 182, which is shown more clearly in the side view of Figure 46.

Rear and bottom views of device 170 show rear 188 and bottom 186 sides in Figures 4H and 4I, respectively.

A lens 65 suitable for magnifying the image of a 15 microdisplay for viewing by a user is illustrated in the example of Figure 5A.

For a 0.25 inch diagonal microdisplay, the outer diameter 64 of the lens can be about 30.4 mm, the thickness 70 of the lens at the optical axis 67 can be about 8 mm, 20 the inner surface 60 that receives light from the display has a curved diameter of about 21.6 mm, and the viewing surface 61 has a diameter of 68 of about 22.4. The peripheral edge 69 used to hold the lens in the assembly can have a thickness 66 of about 2 mm and a radius 71 of 25 about 4 mm. The lens 65 can be made of glass or a plastic material such as acrylic. This particular example of such a lens has a 16 degree field of view and an ERD of 25. The lens assembly can include an automatic focusing system, or a lens system that collapses in size when not in use.

30 Another preferred embodiment for providing a color display can use a diffraction optical system such as those described in application U.S. Serial No. 08/565,058 filed on November 30, 1995, the entire contents of which is incorporated herein by reference.



Another preferred embodiment of a 1.25 inch diameter lens system 52 with a larger field of view is illustrated in Figure 5B. Three lens elements 51, 53 and 55 enlarge the image on the display 54.

5       The lens 65 of Figure 5A can be used in the alternative display assembly of 80 of Figure 5C. In this embodiment, the display 82 is positioned between the backlight housing 84, containing LED 86, and the lens housing 88 that holds the lens 65 in a fixed position  
10 relative to the display 82.

A microdisplay system 360 utilizing a folded optical path is illustrated in connection with Figure 5D. In this embodiment, an LED array 362, or other light source, illuminates the display within housing 364. The display  
15 366 directs an image along a first optical path 372 that is reflected by mirror 368 along a second other path 374 through the lens 370 as described previously.

Another preferred embodiment of the backlight system is illustrated in Figures 5E-5G. The backlight 375  
20 includes a reflective bowl 376 with an inner concave surface 382 that reflects light emitted by the LEDs 380 onto the active matrix region of display 377. The LEDs 380 are mounted on a circuit board 378 that is electrically connected to the timing circuit described previously. The  
25 system 375 can also include a heat sink 379 for applications requiring thermal isolation of the display circuit from the backlight circuit. The element 379 can be a silicon carbide, silicon, or aluminum nickel plate or wafer. The element 379 can be a silicon carbide, silicon,  
30 or aluminum nickel plate or wafer. The element 379 can be insulated from the display 377 with layer 381 such as an adhesive. The circuit board 378, element 379 and optional layer 381 have openings that are aligned to provide an aperture 383.

A preferred embodiment of printed circuit board 378 on which the LEDs are mounted is shown in Figure 5F. In this embodiment 18 blue, green and red LEDs 386 are positioned around opening 384. Another preferred embodiment utilizing 5 8 LEDs 386 is illustrated in Figure 5G. Fewer LEDs allow the circuit to operate at lower power. Additionally, for color sequential operation, where frame rates are relatively high, the LEDs are driven at higher rates to increase brightness.

10 Another preferred embodiment of a backlight is illustrated by the system 390 of Figure 5H. In the embodiment the circuit board 395 on which the LEDs 396 are mounted is positioned underneath the reflective bowl 394 with the LEDs 396 mounted on a post 399 extending through 15 opening 398. Light is diffusely reflected by bowl through diffuser 392 onto display 391.

Figure 5I illustrates a backlight housing 84 with an aperture on one side through which light exits the housing and is directed through the display. The housing has a 20 base and sides 135 in the folded opened view of Figure 5J. The display is mounted onto plate 393. The display 391 can be connected to external connectors 137 by flexible circuit boards 136 which wrap around the sides of the bowl. The backlight housing preferably has a volume of less than 0.5 25 cubic inches. The display module preferably has a volume of less than 2 cubic inches.

#### Lighting System for Reflective Liquid Crystal Display

The details of a lighting system 102 for a reflective micro, display of the invention will now be described in 30 connection with Figure 6. Illumination for a reflective LCD system 500 based upon the active matrix circuit described heretofore in connection with Figure 2 is provided by an array of Light Emitting Diodes (LED(s)) 501

disposed adjacent light-diffuser 505 which uniformly transmits the source LED light to a linear polarizer 502.

The linear polarized light 516 from polarizer 502 is passed to a polarizing beamsplitter or prism 508 which is reflected by beam beamsplitter 508 and is incident on specularly reflective LCD 506 to provide the requisite illumination. The light incident on LCD 506 is selectively reflected to generate an image that is rotated by 1/4 wave plate 504 so that it is transmitted through splitter 508 and through lens 510 to the observer 512.

Shown in Figures 7A-7C are preferred embodiments of an LED backlighting system utilizing a diffuser for a transmission display in accordance with the invention. In a first embodiment of an LED illumination system 400 shown in Figure 7A, blue (B)402, green (G)404, and red (R)406 LEDs are optically coupled to a flat diffuser element 408 around the periphery of an illumination area of 410 that is positioned adjacent the display active or viewing area. For a display having a diagonal of 6.35 mm, the side of 412 of the viewing area 410 can be about 3.81 mm in size, and the length 414 of the viewing area can be about 5.08 mm. The diffuser 408 can be a plastic material such as acrylic and the back of the diffuser can be coated with a reflective material to improve light output of the device.

In another embodiment of an LED display illumination system 420 as shown in Figure 7B, the LED's 422 are coupled in pattern to the edge of the diffuser 408. The LEDs 422 are actuated in sequence 407 to provide color sequential operation with fewer LEDs.

In the system 430 of Figure 7C, the display 432 is coupled to an angled diffuser 436 at interface 440. The linear array of LEDs 434 are coupled at one end of the diffuser and a reflective back surface is designed to evenly distribute light as it is directed through the interface.

Illustrated in connection with Figure 8 is a cellular telephone 200 having a magnified microdisplay in accordance with the invention. The display can be included in a base portion 210 of a "flip-phone" along with keypad 218 and  
5 microphone 220. The speaker 206, or the display or a second display as well as additional circuitry can be included in second portion 208 that rotates relative to the base 210. An antenna 204 can telescope out of the base for improved wireless reception. A battery is housed at 212.  
10 A lens 202 can be viewed by the user while holding the speaker to his or her ear thus enabling both viewing and voice transmission at the same time. The display can be turned on or off at switch 216 to save battery life when the display is not in use. The magnification can be  
15 adjusted at knob 214.

Additionally, a small camera 215 such as a charge coupled device (CCD) or other solid state imaging sensor can be mounted on a telescoping element to provide an imaging or video-conferencing capability. The camera can  
20 be pivoted so that the user can point and hold the camera in any selected direction. The image generated can be seen on the display and/or transmitted to a remote location, selected buttons or touch pad keys 218 can be used as a mouse control for the display.

25 Alternatively, the display can be formed in a modular component that snaps onto the base portion of a standard telephone and couples to a display circuit port in the base section of the telephone. This is illustrated in the preferred embodiments of Figures 9A - 9J.

30 Figure 9A shows a telephone 250 having standard features such as a display 252 and a port 254 for external communications. The modular display unit 260 shown in Figure 9B is configured to dock with the telephone 250 wherein the connector 268 is inserted into port 254 and  
35 latch 264 connects to the top of the base section of

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telephone 250 thereby connecting the micro display within display subhousing 262 to the receiver within the telephone 250. The subhousing 262 pivots relative to main housing 270 to allow viewing of the display through lens 267 during use of the telephone 250. In this embodiment, telescoping camera 215 can extend from subhousing 262. Base 270 includes a second battery, drive electronics for the LED backlit LCD display on activation switch 266. Figure 9C is a sideview of telephone 250 showing the battery housing 250 on the opposite side from the speaker 206. Back panel 258 is shown in the rear view of Figure 9D along with second battery contacts 256 exposed thereon. When the telephone 250 is docked in unit 260, the surface 258 abuts surface 265 and connectors <sup>265</sup>~~264~~ are positioned against contacts 256 such that the telephone can be powered by the second battery in housing 270.

Figures 9E, 9F and 9G illustrate top front and side views of unit 260 where the subhousing is shown in both its storage position 274 and its viewing position 272. Figures 9H and 9I show back and second side views of unit 260 and illustrate battery access panel 275, focus knob 276 and control buttons 278 that are exposed on the side of housing 270 when the sub-housing 262 is rotated to the viewing position 272.

In the embodiment 280 shown in Figure 9J the telephone 284 is shown docked with housing 286. However in this embodiment, the display is mounted withing a pivoting unit 282. The user can swing unit 282 along arc 292 to expose viewing lens 288. The user can also swing the display around a second orthogonal axis 294 at joint 298 so that the display rotates into a variety of viewing positions relative to hinge section 290.

Figures 10A and 10B illustrate another docking system for a portable telephone. The element 286 of system 300 includes mouse controls 303 that can be positioned on the

front or rear of the element. The telephone, which can incorporate a touchpad 301, nests within the docking element 286 and is electrically connected to the element through a connecting port as described previously. Part of  
5 the base section houses a display module 306 having a display window 309 and can optionally also include a CCD or CMOS camera 310 in module 305. The modules 305, 306 can be manually or electrically actuated to move between a cavity within the base element and an operating position outside  
10 of the base section. Each module 305, 306 can rotate around axis 308 when in the operating position for easy repositioning by the use. The display can be used as a view finder for the camera. The base section can optionally rotate around the longitudinal axis of the base  
15 section for left or right handed use.

The docking element 286 can also include a PCMCIA card slot 302 and a touchpad on the rear panel adjacent the docking element battery. Slot can receive an image data card on which data can be stored or retrieved.

20 Figure 11 illustrates another preferred embodiment of a docking element 311 in which the display module 312 can be moved along axis 314 between a position within the base section to an operating position outside the docking element housing. The image viewed through lens 313 can be  
25 inverted for left or right handed use.

Another preferred embodiment of the docking element is illustrated in Figures 12A and 12B. The element 315 has a rotating portion on the back of the telephone and includes a display module 316 which rotates around a second axis 318  
30 to expose the viewing port 317. The module 316 can rotate around a third axis for positioning by the user.

Figures 13A, 13B and 13C show side cross-sectional, front and front cross-sectional views of a hand-held rear projection system 320 using a microdisplay. The system 320  
35 includes a microdisplay and backlight assembly 330, a

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projection lens system 326, a reflective screen 328 and optional retractable sun screens 324. The device has a thickness 322 of less than 2 inches, preferably about 1 inch, a height 336 of less than 8 inches, preferably about 5-6 inches and a display diagonal 334 of 4 inches or less, preferably about 3 inches. This provides a system volume that is preferably less than about 40 inches. The rear reflective screen 328 is shown in the front view of Figure 13C at 338 and are surrounded on 3 sides by retractable shades 332 (324). The handle portion can include speakers 338 and an earphone jack 325.

A body worn hand-held display system is shown in Figures 14A and 14B. The hand-held unit 350 includes a microdisplay viewed through port 352 that is controlled by control element 356 and connected by cable 354 to a body worn communications pod 340.

#### Head Mounted Display System

In yet another embodiment of the invention shown in Figure 15A, the HDTV color active matrix display, as described in connection with Figure 2A, is provided with suitable optics and incorporated into a housing 860 and pivotally attached to a headband frame 861 to provide a novel head mounted display system 864. In general, the system 864 is comprised of a unique headband frame 861 and adjustable strap 862 for attaching the system to the user's head, a side-mounted speaker system 866 connected by cable 868 to electronics console 870 attached to the front of the frame 862, a microphone 872 rotatably suspended from speaker frame 874, and the aforementioned display housing 860 dependent from console 870 and electronically connected thereto by cable 876.

Not shown in Figure 15A is a headband system comprised of two or more pads 180A, 180B, as shown in Figures 15B-15E.

To allow for the broadest range of head sizes, the headband frame 861 utilizes two contoured foam pads 880A and 880B, angled, and spaced apart such that both small and large forehead curvature are accommodated. Each foam pad also has two primary contact areas 881 and 883, that act in the same way. When combined with a strap 862 placed below the ball formed at the rear of the head, the net effect is that the headband frame 861 is securely located on the wearer's forehead 887 whether child or adult.

When the electronics are used, there is some heat being generated in the main housing or console 870. Prior art headbands used wide forehead pads which effectively trapped this heat at the wearer's brow. This proved to be quite uncomfortable after extended wear.

The foam pads 880A and 880B displace the headband frame 861 from the user's forehead 887 leaving a gap therebetween which serves as a warm air vent 875 to dissipate warm air generated by the electronics in console 870.

This new embodiment provides a "chimney-like effect" that effectively vents the warm air away from the wearer's face. The foam pads are removably attached, as by Velcro® type fasteners, and covered with terrycloth 861 for improved comfort. Optional additional vents 871 are provided in the console 870.

#### Equivalents

While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.